Docket No.: 15776-1

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of: Levi et al. Serial No.: 10/664,176 Filed: September 17, 2003 For: MULTI-MODE NAVIGATION DEVICE AND METHOD	Examiner: Dalena Tran Art Group: 3661

DECLARATION UNDER 37 C.F.R. § 1.131

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Dear Sir:

I, Robert Levi, declare that:

1. I am a co-inventor of the subject matter claimed in the above-identified non-provisional patent application (U.S. Serial No. 10/664,176).

2. I understand that the application includes the following independent claims:

Claim 1

A navigation device comprising:

an electronic compass to detect an orientation and provide a corresponding heading signal;

one or more motion sensing devices to detect motion along different axis and provide corresponding motion signals; and

a processing unit communicatively coupled to the electronic compass and the one or more motion sensing devices to receive the heading signal and the one or more

motion signals, determine a position and orientation, and automatically provide different navigation information depending on the orientation of the navigation device.

Claim 7

A method of navigation comprising:

determining whether a navigation device is affixed to a user;

obtaining an azimuth heading;

calculating a dead reckoning position if the navigation device is affixed to the user;

providing azimuth heading and dead reckoning position if the navigation device is affixed to the user; and

providing azimuth heading otherwise.

Claim 9

A method comprising:

determining the orientation of a navigation device;

automatically selecting a first motion measurement algorithm if the navigation device is in a first orientation;

automatically selecting a second motion measurement algorithm if the navigation device is in a second orientation; and

providing a position according to the pedometry algorithm selected.

Claim 12

A machine-readable medium having one or more instructions for dead reckoning navigation, which when executed by a processor, causes the processor to perform operations comprising

determining whether a navigation device is affixed to a user;

obtaining an azimuth heading;

calculating a dead reckoning position if the navigation device is affixed to the user;

outputting the azimuth heading and dead reckoning position if the navigation device is affixed to the user; and

outputting the azimuth heading otherwise.

3. Prior to April 23, 2001, my co-inventors and I conceived of a multi-mode navigation device meeting all of the limitations of the above claims.

4. From before April 23, 2001, until the filing of provisional patent application 60/412,348 on September 20, 2002, from which the present application claims priority, my co-inventors and I employed due diligence in reducing the invention to practice.

5. Prior to April 23, 2001, I prepared an invention disclosure memorandum (Exhibit A) describing the navigation device methods claimed in U.S. Patent Application No. 10/664,176.

6. Prior to April 23, 2001, I prepared a detailed report, part of it found in Exhibit B, on an implementation of the invention where the use of accelerometers to determine orientation is disclosed (page 17, paragraphs 1-5; page 22, paragraphs 1-4).

7. Prior to April 23, 2001, I prepared another report, Exhibit C, which describes how orientation can be used to control the performance of a navigation device, such as an electronic compass (page 3, paragraph 3).

8. I detail below how Exhibits A, B, and C disclose every limitation of independent claims 1, 7, 9, and 12 of the present application. Exhibits A, B, and C, referred to herein, have been redacted to remove all dates thereon. However, all such dates are prior to April 23, 2001, the Ladetto patent filing date.

Independent Claims

Claim 1

A navigation device comprising:

In Exhibit A, page 1, paragraph 1, an "[e]lectronic magnetic compass" is disclosed and in page 2, paragraph 5, an "electronic pedometer" is disclosed. Both of these are navigation devices as claimed.

an electronic compass to detect an orientation and provide a corresponding heading signal;

Exhibit A describes an electronic magnetic compass that provides "indication of direction with respect to magnetic North" (page 1, paragraph 1) and a plurality accelerometers to determine orientation relative to the horizontal plane (page 2, paragraph 3).

one or more motion sensing devices to detect motion along different axis and provide corresponding motion signals; and

Exhibit A describes the use of "[t]hree silicon accelerometers ... oriented at right angles to each other" (page 2, paragraph 2) and interfaced to a microprocessor that receives the signals from the accelerometers (page 2, paragraph 1).

a processing unit communicatively coupled to the electronic compass and the one or more motion sensing devices to receive the heading signal and the one or more motion signals, determine a position and orientation, and automatically provide different navigation information depending on the orientation of the navigation device.

Exhibit A describes a microprocessor (page 2, paragraph 1) coupled to the magnetometers - making up the electronic compass - (page 2, paragraph 1) and one or more motion sensing decices (i.e., accelerometers) to determine position and orientation (page 1, paragraph 1; page 2, paragraph 5). Exhibit C teaches a module (i.e., navigation device) that provides different navigation information depending on the orientation of the navigation device (page 3, paragraphs 3 – " '[o]rientation' is the

specification of which module axis is take as 'up' and which is 'forward'. This permits ... to reorient a module quickly.").

Claim 7

[D]etermining whether a navigation device is affixed to a user;

Exhibit A teaches that the navigation device (i.e., compass) may be "mounted in a waist or belt holster" (page 1, paragraph 4) and that the navigation reorients it axis based on whether it is in the holster or hand by hand.

obtaining an azimuth heading;

Exhibit A teaches that the the navigation device (i.e., compass) provides an "indication of direction with respect to magnetic North" (page 1, paragraph 1).

calculating a dead reckoning position if the navigation device is affixed to the user;

Exhibit C teaches a module (i.e., navigation device) that provides different navigation information depending on the orientation of the navigation device (page 3, paragraphs 3 – " '[o]rientation' is the specification of which module axis is taken as 'up' and which is 'forward'. This permits ... to reorient a module quickly.").

providing azimuth heading and dead reckoning position if the navigation device is affixed to the user; and

Exhibit A teaches that "when a user's compass was mounted in a waist or belt holster that positions the compass reference plane approximately vertical" (page 1, paragraph 4) and "[a]t the magnetic North Pole, the field is entirely vertical" (page 1, paragraph 2); and dead reckoning via a pedometer (page 2, paragraph 5).

providing azimuth heading otherwise.

Exhibit A teaches "a magnetic compass ... provide[s] an azimuth angle that lie in a horizontal plane tangent to the earth at the user's position." (page 1, paragraph 1).

Claims 9 & 12

determining the orientation of a navigation device;

Exhibit A teaches a plurality accelerometers to determine orientation relative to the horizontal plane (page 2, paragraph 3).

automatically selecting a first motion measurement algorithm if the navigation device is in a first orientation;

Exhibit C teaches "that the module orientation for which the [compass deviation] table is valid is stored with it, and the firmware will not use the table if it is configured for another orientation." (page 3, paragraph 3)

automatically selecting a second motion measurement algorithm if the navigation device is in a second orientation; and

Exhibit C further adds, "multiple deviation table and orientation combinations could be maintatined in software if the ability to reorient is desired. One possible application would be when the soldier assumes a prone or crawling position." (page 3, paragraph 3)

providing a position according to the pedometry algorithm selected.

Exhibit A teaches dead reckoning via a pedometer (page 2, paragraph 5).

I hereby declare that all statements made herein of my own knowledge are true and that the statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under section 1001 of Title 18 of the U.S. Code and that such willful false statements may jeopardize the validity of the application of any patent issued thereon.

Date: 11 MARCH 2005

Robert Levi

Patent Claims
for
Horizontal Plane Resolution for Electronic Compasses

1. Introduction. Electronic magnetic compasses have been built using a variety of magnetometers and other sensors, but all magnetic compasses are intended to provide the user with an indication of direction with respect to magnetic North. Implicit in the direction or azimuth information is that the data contains a purely horizontal indication. A magnetic compass is intended to provide an azimuth angle that lies in a horizontal plane tangent to the earth at the user's position and referenced to the component of the earth's magnetic field vector that also lies in that plane.

At any arbitrary location the earth's magnetic field vector consists of both horizontal and vertical components. At the magnetic North Pole, the field is entirely vertical and at the magnetic Equator the field is completely horizontal. Unless compensating measures are taken substantial errors may be introduced into the compass sensors that result from the sensors being tilted out of the horizontal plane. For example, in the mid-Latitudes of the United States a tilt of 1 degree can produce an azimuth error of 2 degrees. This occurs because the compass sensors cannot determine the difference between increasing vertical field components caused by tilt and change in horizontal components due to rotation.

Mechanical compasses accomplish the indication of the horizontal component by using a gimbal that seeks a level horizontal plane using gravity. Mechanical gimbals can also be used with electronic compasses. Electronic compasses have also been compensated for tilt using electronic tilt sensors such as electrolytic level sensors and accelerometers for determination of the horizontal plane. In these configurations, two sensors are used since the static mounting plane of the compass is known in advance. The above methods are all limited to approximately a maximum tilt of ± 90 degrees, due either to mechanical gimbal lock or sensor range limits.

The invention described below will allow an electronic compass to be used in literally any orientation without prior knowledge of the static mounting orientation of the compass reference plane with respect to the horizontal plane. This feature would be useful, for example, when a user's compass was mounted in a waist or belt holster that positions the compass reference plane approximately vertically. If the user removes the compass from the holster and holds it in his hand, the compass reference plane will become oriented approximately horizontal.

Exhibit A

2. Claim Summary. The invention uses three accelerometers mounted in an orthogonal triad for tilt compensation of a triaxial magnetometer. A microprocessor interfaced with the accelerometers calculates the direction of the gravity vector with respect to the triaxial magnetometer reference plane. An algorithm is then used to determine which of the three magnetometers is most nearly horizontal. The proper magnetometer outputs are then combined to resolve the horizontal component of the earth's magnetic field relative to the compass reference vector. The total resultant magnetic vector may also be calculated and used to compensate for unexpected magnetic disturbances. The claims also include using the horizontal accelerometer for the navigation pedometer that is described in our earlier patent application.

3. Tilt Compensation using an Accelerometer Triad. Three silicon accelerometers are oriented at right angles to each other and parallel to the sensitive axis of three separate magnetometers. Each accelerometer sensor is oriented with its sensitive axis to measure accelerations in X, Y and Z directions. Only two accelerometers are required at a time to measure tilt with respect to a horizontal plane. The third accelerometer is provided for use as a pedometer and to allow the instrument to be used in any arbitrary attitude. The horizontal plane is selected as described below by the system's microprocessor. Magnetic components associated with each of the two accelerometers used to measure tilt are resolved by a vector arithmetic algorithm into horizontal and vertical components.

4. Determination of the Horizontal Plane. The horizontal plane is identified by finding the accelerometer with the largest static output value. The static value is proportional to the acceleration of the earth's gravity. An accelerometer mounted with the sensitive axis in the horizontal plane will read a value of 1 G. An accelerometer mounted in the vertical position will read 0 G's, neglecting bias effects. An accelerometer that is most nearly horizontal will indicate the largest value. Vector arithmetic may also be performed on the three accelerometers to account for situations where no single sensor is clearly the maximum. Reliable use of this method depends on determination of the accelerometer's static bias values when the system is first initialized. Accelerometer bias must then be predicted or compensated for temperature induced drift effects.

Also assumed is that the inertial accelerations produced by movement of the body on which the instrument is mounted may be neglected. This is a good assumption for users on foot, especially since only the steady state values of acceleration are used for horizontal plane determination.

5. Pedometer combined with Tilt Sensing. An electronic pedometer may be implemented using an accelerometer as described in our earlier patent application. The pedometer function may be combined with the tilt sensing function in this invention, thereby saving the need for additional sensor hardware. This combination is feasible since the tilt sensing uses the static or low frequency information, while the pedometer uses frequency components up to 5 Hz. The appropriate components are separated from the accelerometer signal using digital signal processing filters. The

Exhibit A

tilt component results from the output of a low pass filter with a cutoff frequency of approximately 0.05 Hz. The pedometer signals are retrieved from the output of a high pass filter that passes signals in the range from approximately 0.25 Hz. to 3 Hz.

6. Detection of Unexpected Magnetic Disturbances. In addition to calculation of the horizontal component of the earth's magnetic field, the vertical component and the total field vector may also be computed using the triaxial magnetometer and tilt sensor. By comparing the computed vector with a known reference vector for the user's location, the effects of external magnetic disturbances can be measured and canceled by a compensation algorithm. To uniquely define the disturbances that produce an anomoly in the magnetic vector, approximately 5 measurement samples may be required to calculate all components of the polynomial that describes the disturbance function. These would be solved as 5 simultaneous equations.

The reference vector may be obtained by several methods. The total vector, strength and direction, is a constant for any given location on earth. The magnetic field vector of the earth has been mathematically modeled by the U.S. Geological Survey and is known as World Magnetic Model. New coefficients for this model are published every five years. If the compass user's position is known approximately then the model may be used.

As an alternate to the magnetic model, the system may be initialized while located in a magnetically undisturbed area. During initialization, the field components would be recorded by the magnetometers and converted to a reference vector. The reference vector could then be used for comparison within the local geographic area.

Signed by Inventors: Robert W. Levi, Charles T. Judd, Steven J. Davis

Robert W Levi

Robert W. Levi — Date

Charles T. Judd

Charles T. Judd — Date

Steven J. Davis — Date

Exhibit A

the existing performance may be adequate. Validation of the metabolic calculations remains to be performed. Even though the results look reasonable, validation using oxygen uptake or other laboratory methods will be required to ensure accuracy.

6.2 Activity, Step/Impact Characterization, and Body Orientation

Triaxial accelerometers are a rich source of information about the motion of the person wearing them since almost any movement of the subject creates accelerations in addition to that of gravity. If gravity is somehow cancelled out, what remains is the subject's physical activity. Correspondingly, if the subject's physical activity is somehow cancelled out, what remains is gravity, which can serve as an indication of body orientation—standing vs. lying down, for example.

Since the acceleration due to gravity is constant, it can be removed by high-pass filtering of the accelerometer signals. Conversely, the subject's motions can be minimized by low-pass filtering, which leaves gravity as the predominant result. Each filtering technique can contribute useful information about a soldier's condition.

The relative direction of the gravity vector, determined by low-pass filtering, is a measure of body orientation. Determining orientation through low-pass filtering produces a lag or delay in reported information so that only orientation changes lasting more than a few seconds can be reported, but this should not impair the usefulness of the information.

High-pass-filtered acceleration data can be incorporated into an "activity index." The concept is similar to a wrist acceleration monitoring system described by Redmond and Hegge (Reference 5), but the activity index described below uses torso accelerations rather than wrist accelerations since the DRM accelerometers are mounted on the subject's trunk. This is certainly different than wrist monitoring since trunk motions generally require more effort. However, we are not aware of any research into the relative merits of the two monitoring methods.

The activity index described below is a single number which can be applied to periods of any duration and which indicates the amount of activity during that period. Once a correlation is developed between the activity index and normal walking, the index would correlate with distance traveled only when walking is the primary activity. A different ratio would imply other activity. Also useful would be an indication of very low activity, which would indicate sleep or being unconscious, especially if body orientation is also being reported as prone. It is possible that the activity index correlates with metabolic requirements and, if so, could account for activities in addition to walking or running. Future work will be required to establish correlation of the body activity index to various activities and to devise algorithms to use this information.

One way to implement a high-pass filter is to subtract the output of a low-pass filter from its input. This permits creating both types of filtering with only one filter, a low-pass in this case, and is the method used in our experiments. Low-pass filtering with a cutoff frequency of about 0.05 Hz was applied separately to the data from each axis. The resulting high-pass filtering has the same cutoff frequency.

6.2.2 *Body Orientation*

As described earlier, low-pass-filtered accelerometer signals can be used to determine and report body orientation. This can be done either as a pair of angles calculated as for step/impact characterization but using low-pass-filtered data instead, or as a simple code providing the same type of information in a qualitative way.

The second approach was implemented in the firmware of a production DRM. The code output was based on the concept of a cube surrounding the module; one of six codes are reported depending on which face of the cube is closest to facing downward. Adding this information to the module's usual position-reporting message presents no problems and offers a simple and valuable clue as to a soldier's orientation. When combined with other information, notably the activity index and step/impact characterization, a wounding event could be deduced.

6.2.3 *Conclusions*

A substantial amount of useful information can be derived from accelerometers worn by the subject. The most helpful data is likely to be body orientation and a physical activity index based on the time integral of high-pass-filtered acceleration magnitude. Processing of this data could contribute to detecting wounding events and assessing the soldier's general condition, however, additional work is required to develop a methodology for utilizing the data.

The computational requirement to report body orientation as a simple code is slight and can be inserted into a system which includes dead reckoning with no noticeable extra burden. The computations required to support other information from accelerometers is greater and may require additional computation resources.

6.3 Respiration Rate Determination

Three sensors were explored for measuring respiration: accelerometers, the barometric altimeter, and a voice microphone. Since respiration is a basic vital sign, the objective is to provide an indication that is suitable for fielding and does not require the attachment of any peripheral device such as a chest strap. Accelerometer signals were also investigated for heart rate measurement.

6.3.1 *Sensing Respiration With Accelerometers*

Using the DRM accelerometers for measuring respiration includes the assumption that the DRM could be mounted in a body location that is both suitable for respiration measurement and navigation, if only one device per soldier is employed. Such

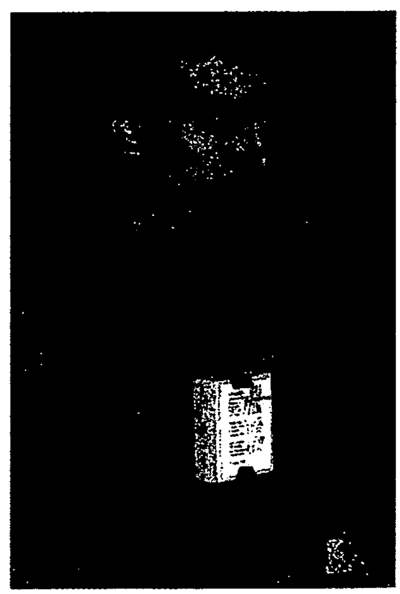

Figure 11: Module Positioned for Sensing Respiration

Section I, Introduction

The objective of the SBIR Phase II project is to upgrade the existing hardware and software for the Dead Reckoning Module (DRM), implement physiological monitoring functions, integrate the DRM with the WPSM wireless network, and produce and test the upgraded units in field exercises. The deliverable items include 12 each new DRMs complete with C/A Code GPS receiver, antenna and batteries, updated version of DRMHost software, and a revised Programmer/User Guide. Engineering support, monthly reports, annual reports and a final report will also be provided.

Section II, Progress Description

Electronic Hardware: All of the new modules that are built have been tested and calibrated. Two of the GPS receivers were questionable and were replaced. The hardware kits have been released to the assembler for fabrication of the 12 deliverable modules.

We have added an internal compass deviation table to correct for small errors on the order of 1-2 degrees. This has been a feature of our earlier designs, but, it has the drawback of being valid for only when the unit is level. We did not want to add it until we had evaluated the other compensation techniques that we have developed.

The deviation table permits "trimming" the compass to accuracies of better than one degree, so it is a worthwhile addition. However, after applying our new "vector calibration" we are seeing compass errors of less than three degrees before deviation corrections, which is better than we have seen with earlier designs. Our calibration strategy is substantially the same as before, but we have overhauled our methods for performing it. Between the new circuitry and the new methods, we seem to be achieving noticeably better compass accuracy.

Our calibration process includes correcting for fixed magnetic anomalies, and we have experimented with calibrating a unit with a steel plate taped to it. These experiments highlighted a circuit board layout problem: the three magnetometers are not mounted as closely together as on earlier units. They are as much as an inch apart. The mathematical model on which anomaly compensation is based assumes that the magnetometers measure the magnetic field at a single point. Since they don't, our ability to correct for a strong, close-in magnetic influence is impaired.

This is a problem only for strong magnetic influences within an inch or two of the module itself, so we do not plan a board redesign for this reason alone. During our next board redesign, however, we will place the magnetometers as close together as possible.

GPS antennas were received, but the supplier installed magnets in the base, irrespective to our instructions to the contrary. The magnets can be removed by heating them to soften the adhesive, however we have yet to verify that the heating does not damage the internal antenna components.

Batteries:. The alternate battery supplier agreed to make batteries for our application using "hand" tooling. Several thousand batteries could be produced from the hand tooling. A purchase order for 1150 maHr Li-Ion Polymer batteries at $25 each has been placed with

Exhibit C

delivery expected approximately by mid-May. The higher priced $100 each, 1200 maHr batteries are due for delivery by the end of April.

Packaging:. The drawings were modified and our preferred machine shop has accepted the job of producing the deliverable housings. Three "first article" units have been received with the remainder required for the deliverable 12 should be available by early May. Drawings were made for nylon pouches to hold both the GPS antenna and the DRM unit. These will be made from ballistic nylon and velcro. The antenna pouch will be designed to attach to the shoulder strap of a load bearing harness or to an epaulette.

Firmware:.. Support for the compass deviation table has been added. The table itself is prepared externally in DRM3Cal and loaded into the module. One feature of this firmware implementation is that the module orientation for which the table is valid is stored with it, and the firmware will not use the table if it is configured for another orientation. "Orientation" is the specification of which module axis is taken as "up" and which is "forward." This permits us to reorient a module quickly, although the particular deviation table may no longer be valid. However, multiple deviation table and orientation combinations could be maintained in software if the ability to re-orient is desired. One possible application would be when the soldier assumes a prone or crawling position.

Support for additional initializations has now been added. These include specifying latitude and longitude, stride, body offset, magnetic declination, and altitude via a software message. Kalman filter code will be the same as before as much as practical. Since this filter will operate as a true, pre-empted background task, its interface with the other tasks must be protected by "mutexes," and this is one of the adjustments which the code will require. Another adjustment is to remove the explicit yielding which the filter had to do before in the prior co-operative task switching environment. Foreground/background context switching and mutex support have been in place for some time and have been exercised with test routines, so things should work without much trouble.

Support Software:. The Windows program "DRM3Cal" has been expanded to support the deviation table calibration process and the initializations described above. Source code for this program now exceeds 12,000 lines, which puts it in a class of fairly complex programs.

For some time, DRM3Cal has been able to open a logging file to which several parameters are written. It has received records of the calibration process for each module, but it has now been expanded to receive regular status records containing basic data similar to those provided by the older DRMHost and XYLL. The records output by DRM3Cal (and the planned DRM3Host) are in formatted ASCII and require no further processing, which is an improvement over the prior system that required a separate program to convert from binary to ASCII format.

Section III, Problem Areas

None at this time

Section IV, Next Month
Implementation of the Kalman Filter should be complete. Full-up system tests using both dead reckoning and GPS will be conducted. Fabrication of the deliverable hardware should be nearly complete.

Section V, Administrative Comments
A demonstration is planned of the new system for May 16 at Ft. Benning, DBBL, for use in tracking soldiers during training. The DRM will output data in real time, and interface to the existing wireless modem. We will have three people from Point Research to work with Mr. Ralph Carrizo at the McKenna MOUT site.